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Emerging technologies and timber products in construction – literature review

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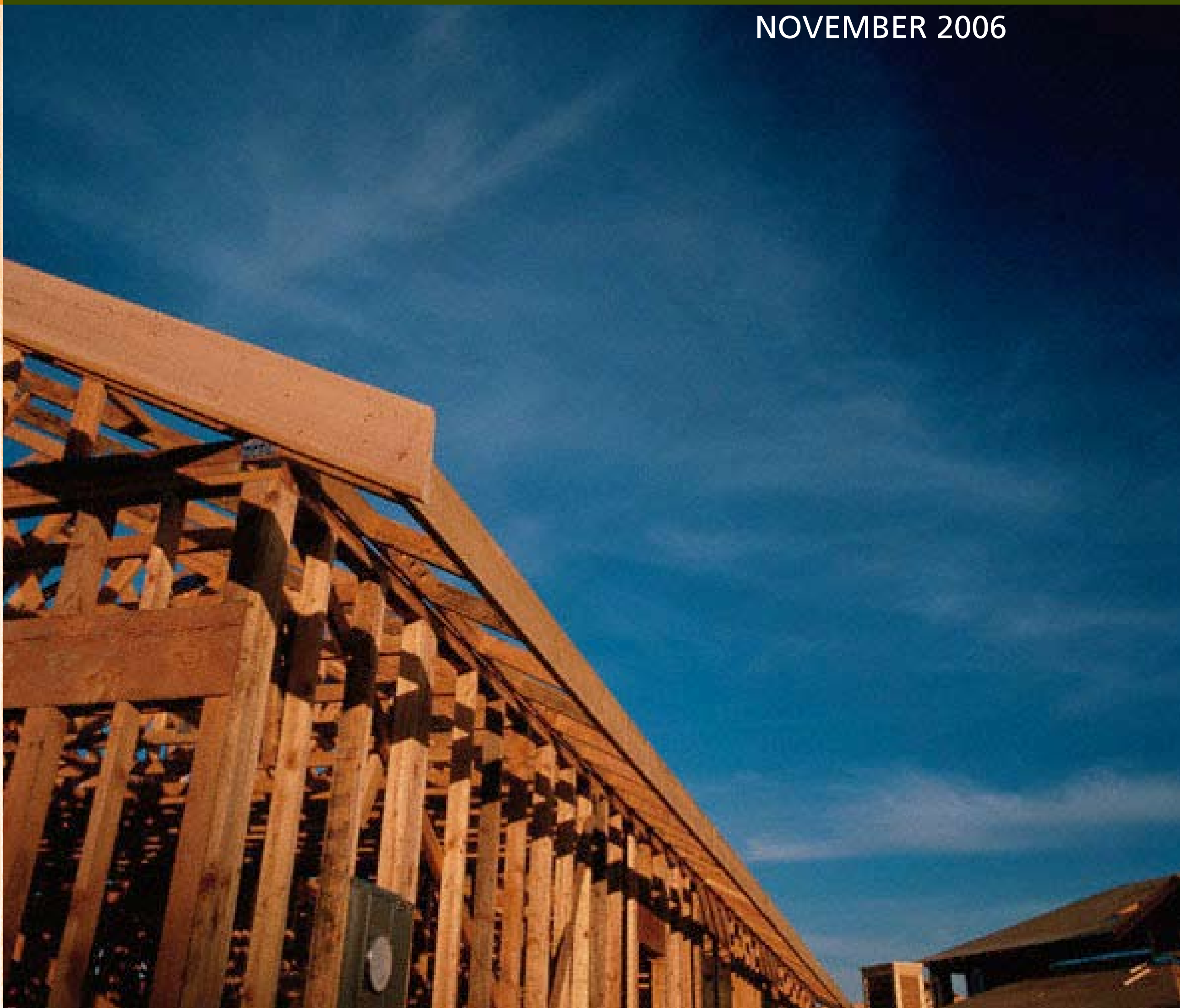

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Emerging technologies and timber products in construction – literature review

Prepared for the

Forest and Wood Products Research and Development Corporation

by

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Table of contents

1. Overview and scope of report

This document contains a review of the recent technical literature related to the project "Emerging Technologies and Timber Products in Construction", funded by the Forest and Wood Products Research and Development Corporation (FWPRDC) of Australia.

The aim of this review is to complement, to contextualise, and to help prioritise a database of emerging innovative technologies, systems and products from different regions of the world, which may be applicable in the Australian timber construction industry. The database is being developed from the work of a group of international consultants who have been engaged on the project to undertake a survey and analysis of innovative technologies from four different regions of the world.

Technologies included in the database are those relevant to site and/or factory assembled, two and three dimensional components and systems which are used in the following types of timber buildings:

- Single detached housing
- Multi-residential housing including attached, flats, units to three to five stories and
- Single storey 'light framed' commercial/industrial buildings

For the purposes of this review, 'technical literature' refers to refereed journals, conference proceedings, and public domain technical and industry reports. In the main, *specific* technologies that are developed for the timber construction industries are not published in this form (for obvious commercial reasons), and hence, this review does *not* contain an exhaustive listing of all applicable systems, products and technologies that exist. In the next phase of this project, a compendium of more specific innovative technologies and products will be compiled from the database referred to above. The compendium will contain detailed descriptions of these technologies and the benefits and limitations with reference to a range of categories and criteria.

To avoid overlap with the compendium and the work of the consultants, the scope of this review is therefore limited to drivers and future directions for innovative timber construction systems, and an overview of the key existing and emerging generic technology areas, product types and application areas which may be important in the future.

2. Project summary

Timber framed house and light commercial building systems and technology in Australia is, in the main, mature construction technology. Whilst the current site-based and trade-focused practices are considered very cost efficient by world standards, there are emerging pressures on traditional timber construction which may threaten the market share. These pressures include regulatory impost (sustainability in construction, life cycle analysis and durability, energy efficiency, bushfires, etc), competitive alternative materials and systems (steel, lightweight fibre cement, insulated panels, etc), aesthetic style and design trends, shortages of skilled labour, and emerging technologies (computerised manufacturing, mass-customisation, nanotechnology, etc). New and emerging technologies could become increasingly relevant to the construction sector in Australia if the construction process moves away from the site-built focus, towards a ‘manufacturing’ or ‘mass-customised product’ paradigm. Any shift along these lines could have big ramifications for the timber industry, particularly if it is unable to embrace or compete with such innovations.

Despite the acknowledged efficiency of Australia’s timber framed house construction industry, there are still significant potential triple-bottom-line benefits that could be achieved. A key task in this project is to assess the potential economic and environmental benefits which can be realised through the adoption of new and emerging technologies. The direct economic benefit to industry is easily summarised by considering the potential losses or gains related to housing. A 1% swing either way represents an annual loss or gain in retail timber sales of up to $10 million per annum in Australia. There is also still a large potential margin for gains in cost efficiency, considering that the cost to the consumer of the base structure of a house is still many times more than the cost of the materials that go into it.

The potential environmental benefits to be gained from improved processes, systems and new technologies are also significant in terms of recycling, waste and pollution minimisation, energy efficiency and greenhouse gas reduction. Given the increased regulatory requirements, and consumer awareness around these issues, demonstrable ‘greenness’ will also help to sustain or increase market share, and inevitably flow on to economic benefit in the medium to long term.

Challenges and opportunities exist for the timber industry to review new and emerging national and international timber building systems, new technologies and trends, and to assess which opportunities have the most potential in an Australian context.

The aim of this project is to conduct an international survey and scoping study on innovative building products/systems and new technologies relevant to light-framed timber construction, and to predict which of the technologies and systems examined could have the greatest potential impact, and greatest chance of successful implementation in the Australian industry context. This will be achieved through a detailed analysis of the real and perceived business and environmental benefits that can be generated from these innovations when they are mapped onto the Australian construction industry structure, capability and ethos, market forces and regulatory environment. An examination of the current and potential future drivers and barriers to the adoption of these new innovations in Australia will also be undertaken.

3. Drivers, challenges and opportunities for the future

The rationale for this study is based on the fact that the emergence of new materials and technologies, could possibly have a significant impact in the largest market sector for timber products – *residential and light-industrial construction*. To put this into context, the following sub-sections outline some of the key drivers, challenges and opportunities which are likely to be influential in shaping future directions. Another FWPRDC project, "Scenario-based Forecasts for Select Timber Markets" aims to provide a perspective on key factors influencing the wider forest products industry over the next five to 10 years (De Fegely *et al.*, 2006). This project may have relevant findings for residential construction products over this period, and should be referred to in conjunction with the information presented herein.

3.1 Review of construction industry roadmapping studies

The idea of 'crystal-balling' for drivers, challenges and opportunities is not new. Many organisations with links to the construction industry at large have recently undertaken roadmapping and scenario forecasting exercises which have looked to the future, with similar motivations to those underpinning this study. Some of the findings and recommendations of these studies are directly relevant to this project.

One such example is the Building Construction Technology Roadmap (Copper Development Centre, 2004) commissioned by the Australian copper industry to look at future trends in construction, which consumes up to 60% of the world's total copper output each year. The rationale for this study was based on the premise that technological and demographic changes could have a dramatic effect on the uptake of end-use copper products. This lesson was learned the hard way for the copper industry in North America. In the 1800s, power was transmitted around North American cities through copper cables. But as the cities grew, so did the electricity grid and the copper cables that carried power became too heavy to use over such large spans. When large electrical towers were built, a switch was made from copper to aluminium cabling, since aluminium was light and could be hung over long distances. The end result was that the copper industry lost a very large market, and was not prepared. History is littered with similar stories, where products and even entire industries have become completely obsolete because of technological and social change.

The copper industry study highlighted many relevant issues to the timber construction industries, such as demographic changes, sustainability concerns, government regulation, skills shortages, industry consolidation, and emergence of Chinese markets, and also looked at industry-specific, disruptive new technologies such as 'wireless' and telecommunications advances.

The results of the study were based on a series of workshops with input from the construction industry and academia. Ten main characteristics were identified for the 'house of the future'. Interestingly, *number one* on the list of these characteristics was:

> *"Flexibility, modularity and materials - home construction will increasingly rely on prefabrication and off-site construction, allowing infrastructure and technology to be embedded. Houses will also be built to permit greater flexibility in use, occupancy and lifestyle."*

This finding is directly relevant to this project because if future generations of houses do increasingly require these characteristics, then the traditional domestic timber construction sector will need to embrace them, else some other construction system or technique, which can deliver the required flexibility and the desired embedded services and technologies may supersede the current industry in the long term. This conclusion is also highlighted in a number of other studies such as one by Robert Gordon University, "Housing the future: Key Opportunities and Constraints in New Housing Innovation" (Edge *et al*., 2003) in the context of prefabricated housing.

Another Australian construction-industry roadmapping exercise was conducted by the CRC for Construction Innovation - "Construction 2020: a Vision for the Property and Construction Industry" (Hampson and Brandon, 2004). This study articulated nine 'visions' for the construction industry of the year 2020. Although the focus is predominantly heavy construction, three of these 'visions' are directly relevant to this study, namely:

- *Vision One – Environmentally friendly construction*
- *Vision Seven – Off-site manufacture*
- *Vision Eight – Improved process of manufacture of constructed products*

The CRC study highlights that in the heavy construction sector, quality control and site worker safety are significant drivers pushing towards off-site manufacture. These drivers are also highly relevant to the timber house construction sector, as of course are the sustainability issues.

A FWPRDC Study "Regional Industry forums - a Report to Industry" examined trends and indicators specifically relevant to the forest products industries. The study was based on input from industry stakeholders, and its aim was to prioritise R&D investment. Although much of the focus was on timber resource issues, trends relevant to this study were also identified, these included:

- *Changes in industry skills demand and mechanization of workforce*
- *Environmental issues related to products*
- *Changing design specifications for buildings*
- *Occupational health and safety*
- *Industry consolidation*

In a similar vein, the FWPRDC project "Scenarios for Selected Timber Markets" (de Fegely *et al*., 2006) came up with critical drivers of change with respect to timber consumption. The drivers were developed from a workshop attended by various stakeholders from across the entire supply chain of the Australian timber industry. The eight critical drivers which were identified were:

- *Climate change and environmental services (influences and responses)*
- *Political decision making and governance (regulations)*
- *Infrastructure investment and development*
- *Domestic economic growth*
- *Energy costs*
- *Health issues*
- *Skilled labour supply*
- *Australian population and demographics including social change*

The workshop and subsequent analysis also identified a range of priority areas which were common across the majority of future scenarios that were examined, These priority areas include:

- *Development of sustainable building products that have high durability and are cost competitive*
- *Meeting the demands from the shift to higher density living*
- *Development of 'smart' wood composites and engineered wood products*
- *Re-use and recycling of building materials*

Many international studies are also relevant. A US study conducted by the Partnership for Advancing Technology in Housing – "Whole House and Building Process Redesign Technology Roadmap" (PATH, 2003) has the simply and aptly stated vision to "*Build Better Homes Faster, and at Lower Cost*". This statement highlights the importance of *quality* and *cost* as drivers and constraints on the viability for the market success or failure of future products and systems. Another US-based study (Schuler and Adair, 2003) highlighted the impact of demographic changes on housing demand and availability of skilled workers.

Similar themes have emerged from several other international future-gazing exercises, such as European Construction Technology Platform's "Challenging and Changing Europe's Built Environment" (ECTP, 2005) and the UK study "Accelerating Change" (Strategic Forum for Construction, 2002). In addition to the themes identified in the other studies reviewed, these two also covered issues of supply chain fragmentation, and the importance of defining end-user requirements in the form of performance targets.

In summary, although some of the material contained in these roadmapping studies is influenced by particular stakeholder agendas, there is nevertheless a reasonably consistent and credible common thread of themes which could be considered as relevant drivers, challenges and opportunities for this project. These include:

- *Environmental sustainability*
- *Process integration and off-site manufacturing*
- *Demographic and social change*
- *Workforce issues*
- *Human health*
- *Market requirements and business potential*
- *Regulatory environment*
- *Innovation and technology adoption*

How each of these issues and drivers impact on timber construction in Australia is discussed briefly in the following sections.

3.2 Environmental sustainability

Introduction

Today, humanity's 'ecological footprint' is estimated to be over 23% larger than what the planet can regenerate (see Figure 3.1). In other words, it now takes more than one year and two months for the Earth to regenerate what we use in terms of energy and resources in a

single year. (Global Footprint Network, 2006). We maintain this overshoot by liquidating the planet's ecological resources slowly over time.

Approximately one-third of the world’s energy and resources are tied up in the built environment (IBEC, 2005). According to the Green Building Council, buildings and their development are a major contributor to this. Specifically, buildings contribute:

- 42% of ***Energy*** used
- 12 % of ***Water*** used
- 40 % of ***Air Emissions***, and
- 40 % of ***Waste to Landfill***

Given that there is an increasing government and consumer awareness of this impact, sustainability is clearly a major driver for the development of new technologies, products and processes for the construction industry at large.

Key environmental performance attributes for construction products

The importance of sustainability as a driver for innovation in construction is clear. Given that assessment of emerging technologies in this study will examine sustainability impacts, key environmental performance attributes which may be directly relevant to timber construction products are briefly reviewed and discussed in the following paragraphs (based on a paper by Foliente *et al.*, 2004).

Energy

- ***Embodied energy*** refers to the quantity of energy required by all of the activities associated with a production process, including the relative proportions consumed in all direct and indirect supporting activities upstream to the acquisition of natural resources. A typical house contains about 15 times the annual operating energy embodied in its construction. Over a 50 year life, this equates to about 30% of the total life-cycle energy usage.
- ***Operational energy*** includes annual operational energy for a building and its services such as heating, cooling and lighting. Typically, over a 50 year lifespan, 70% of the total life-cycle energy usage is used for operation.
- ***Total Life-cycle energy usage*** is the embodied plus operational energy.
- ***Renewable energy*** includes solar, wind, waste, or other renewable energy sources.

Water

- ***Embodied water*** is the quantity of water removed from the water supply through losses due to process usage, evaporation, wastage and disposal of non-recycled water by all of the activities associated with a production process, including the relative proportions consumed in all activities upstream to the acquisition of natural resources.

Material and Resource Use

- ***Consumption*** is the amount/usage of materials and components for construction, operation and maintenance. Improvements in consumption focus on resource efficiency, which means output (amount and performance attribute of a product) compared to required input (amount of raw materials needed to manufacture the finished product). Buildings are a major consumer of materials since they use land and consume minerals and other natural materials (Roodman and Lenssen, 1995).
- ***Recycle and Reuse***: To reduce debris going to a landfill site and virgin material consumption, recycling of resources used in a building and reuse of materials or structures are considered. The indicators include recycle or reuse amount and their contents.
- ***Waste***: is defined as the total amount of waste material from construction, and demolition.
- ***Service life***: The life cycle impact of products used in buildings includes their replacement over the life of the building. Even though a building product has higher environmental impact in the initial stage (construction stage), it might have less relative impact over the life cycle of building if it has a long life. The indicators of service life include specification of building materials, life expectancy of appliances and fit out, durability of building materials, and maintenance/updating schemes.

Environmental impact

- ***Greenhouse gas emissions***: The main cause of global warming is a result of burning fossil fuels for energy. There are many gases that cause global warming impact such as CO_2, methane, CFCs, and NOx. Buildings are directly and indirectly responsible for global warming due to gas emissions during their life cycle (energy consumption from production and transport of materials and construction of building, and heating, cooling and lighting in building). An indicator for this is annualised greenhouse gas (as CO_2) emission.
- ***Ecotoxicity*** means impact from release of toxic substances during the life cycle of building on an ecosystem. Indicators include all toxic chemicals released into the environment.
- ***Emission to air, water and land***: In addition to environmental impacts, which have already been described above, environmental pollutants and other effluents that flow from buildings throughout their life cycle need to be considered. These environmental pollutants released to air, water and land (ground) are defined as sub-categories such as 'Emission to Air', 'Emission to Water', and 'Emission to Land'.
- ***Biodiversity***: Buildings and urban development are major contributors to the loss of floral and faunal biodiversity (Barnett 2002). Indicators considered are change of species index for building development, wildlife habitat preservation, and biodiversity conservation.

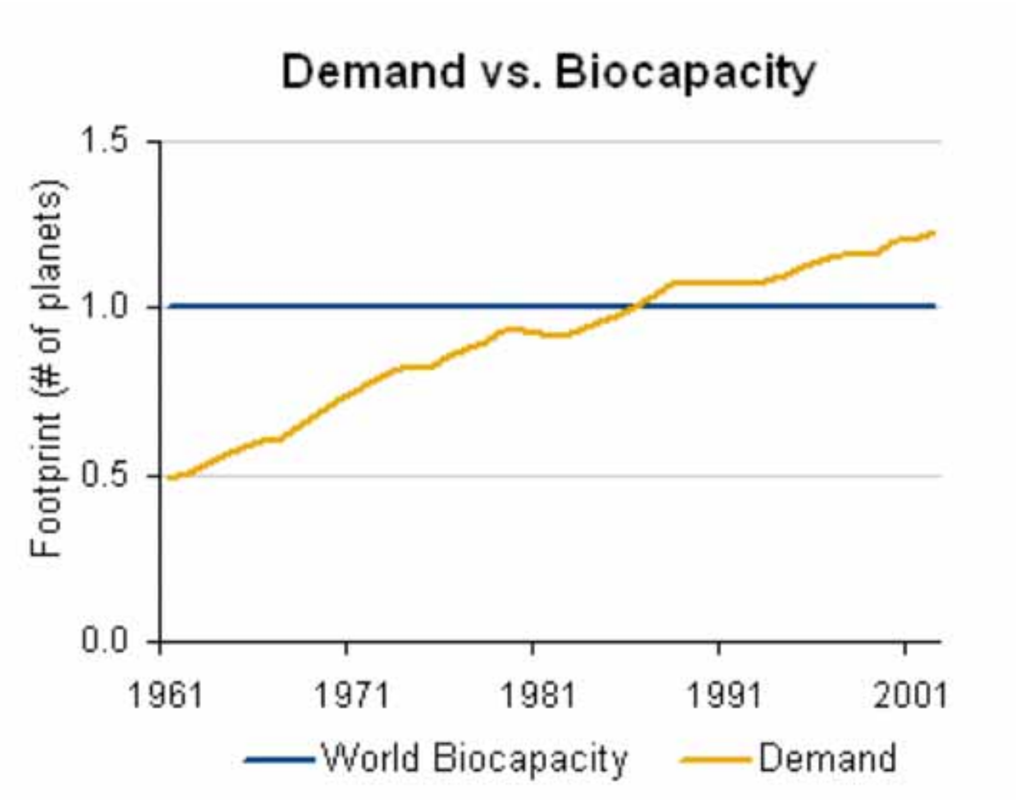


Figure 3.1 - Ratio between the world's 'demand' and the world's 'biocapacity' over time (Global Footprint Network, 2006)

Consumer awareness

Awareness of environmental issues related to the manufacture, use and disposal of consumer products is now firmly established in the developed world, and is increasingly becoming an important driver of consumer choice. This trend was demonstrated to be highly applicable to timber construction products in a recent Canadian survey (Kozak *et al*., 2004). The study showed that although there was little awareness of environmental labelling of end-use wood products in Canada, there was 100% willingness to purchase certified wood products in the future, and a majority willingness to pay a small premium for these products, assuming equivalent quality. Another global indicators of this trend is the rapid increase in the amount of invested money tied up in 'socially and environmentally responsible' investments on the stock exchange (see Figure 3.2).

Rating and assessment tools

As a direct result of the global trend to reduce the ecological footprint, and the increased consumer awareness of the issues around sustainability, there is an increasing use of a range of 'resource accounting' tools, methods and concepts, including sustainability rating and certification systems. Examples of some common consumer product rating schemes are shown in Figure 3.3. Resource accounting tools are also now widely used in the design and assessment of the built environment, across the entire life-cycle.

The timber industry is aware that consumer choice (green consumerism) along with current and future government sustainability policy/regulation can have a big impact on future use of timber products in construction. In 2005, a study "Technical Evaluation of Environmental Assessment Rating Tools" (Seo *et al.*, 2005) extensively reviewed a range of environmental assessment and rating tools for buildings and building products. As shown in Figure 3.4, the application of these tools in Australia encompasses a wide range of activities in the urban development process from selection of individual construction products, right through to assessments of entire sub-divisions.

Rating systems which are applicable to residential or light-industrial construction in Australia include: BASIX, EPGB, EcoSpecifier, NatHERS, AccuRate, BERS, FirstRate and Nabers

One of the key findings from the FWPRDC study was that despite the fact that wood is the preferred construction method for residential construction in Australia, and that wood products can have both positive and negative environmental effects, very few of the relevant existing tools have direct indicators related to wood. If they did, this would enable sustainability comparisons to be made (on an equitable basis) with alternative products. The study recommended that characteristics of wood products which could/ should be included in the indicators include:

- Being renewable;
- Having lower impact on the environment in terms of embodied energy;
- Having lower impact on the environment in terms of air and water pollution;
- Ease of disposal of waste/recyclability, and
- Carbon storage in long life wood structures.

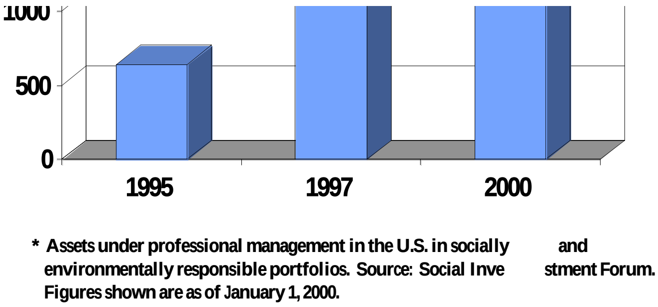
The environmental attributes of timber construction will eventually find their place in the rating schemes, once a full life-cycle inventory is developed for timber products in Australia (including all environmental inputs from forestry through to product manufacturing, construction, use, maintenance and disposal). This inventory is currently under development (in Australia), and has already been advanced significantly for the US market, based on US conditions (Lippke *et al*., 2004)

Although these attributes are not fully recognised in the Australian rating schemes, it is important to consider them when assessing and ranking the products and technologies which will be examined in this study, to determine potential sustainability benefits and liabilities.

Forest certification and associated chain of custody systems are also emerging as important tools for demonstrating the sustainability of timber. There are two major schemes operating in Australia, being the Australian Forestry Standard (AFS), which is recognised internationally under the Program for the Endorsement of Forest Certification systems (PEFC), and the Forest Stewardship Council (FSC) certification program.

Although there has been limited recognition of certification by Australian consumers to date, some green building rating systems, such as the 'Greenstar' rating system, recognise forest certification as a key element in their rating systems. In addition, organizations such as the Green Building Council, who currently only recognise FSC, are beginning to have more influence on timber's specification and use.

Extended Producer Responsibility (EPR) and product stewardship is also an issue and is being promoted by governments and industry internationally and throughout Australia and New Zealand. A major objective of these policies is to address environmental problems, such as solid and hazardous waste reduction, associated with particular products and materials, including timber and treated timber. EPR and product stewardship present a number of opportunities as well as risks for the timber industry. (Mitchell *et al.*, 2006).



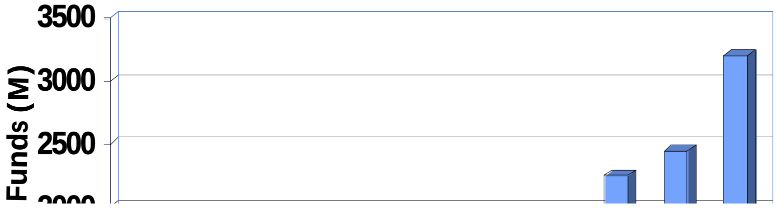


Figure3.2 – Demonstration of the dramatic increase in socially and environmentally responsible investment

Figure 3.3 – Rating schemes for consumer end-products are becoming an important sales driver

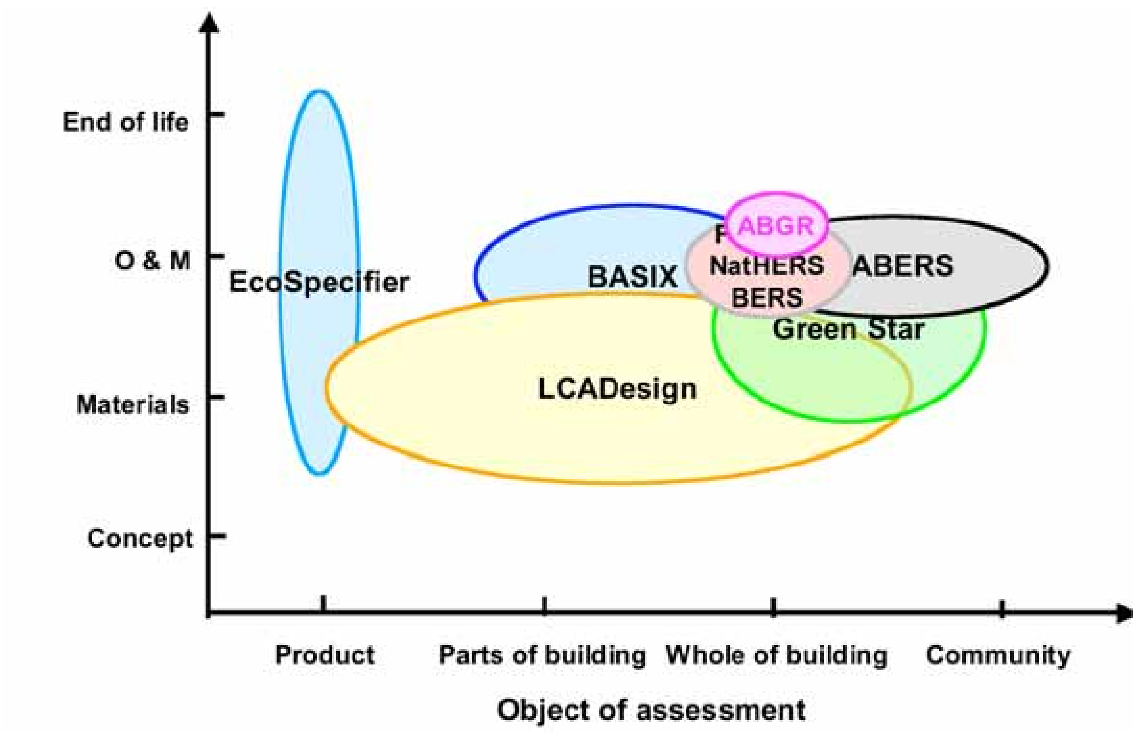


Figure 3.4 - Classification of Australian tools and rating schemes for environmental assessment of buildings and related components (Seo et al., 2005)

3.3 Process integration and off-site manufacturing

There have been many proposals to re-invent the process of design and construction of housing over the last hundred years or so. The concept of the prefabricated dwelling dates back at least, to the beginning of last century. The Sears Roebuck catalogue shown in Figure 3.5 (an example of 'catalogue shopping' in the USA, which introduced the idea of fixed standardised pricing) made prefabricated homes available to subscribers as early as 1908.

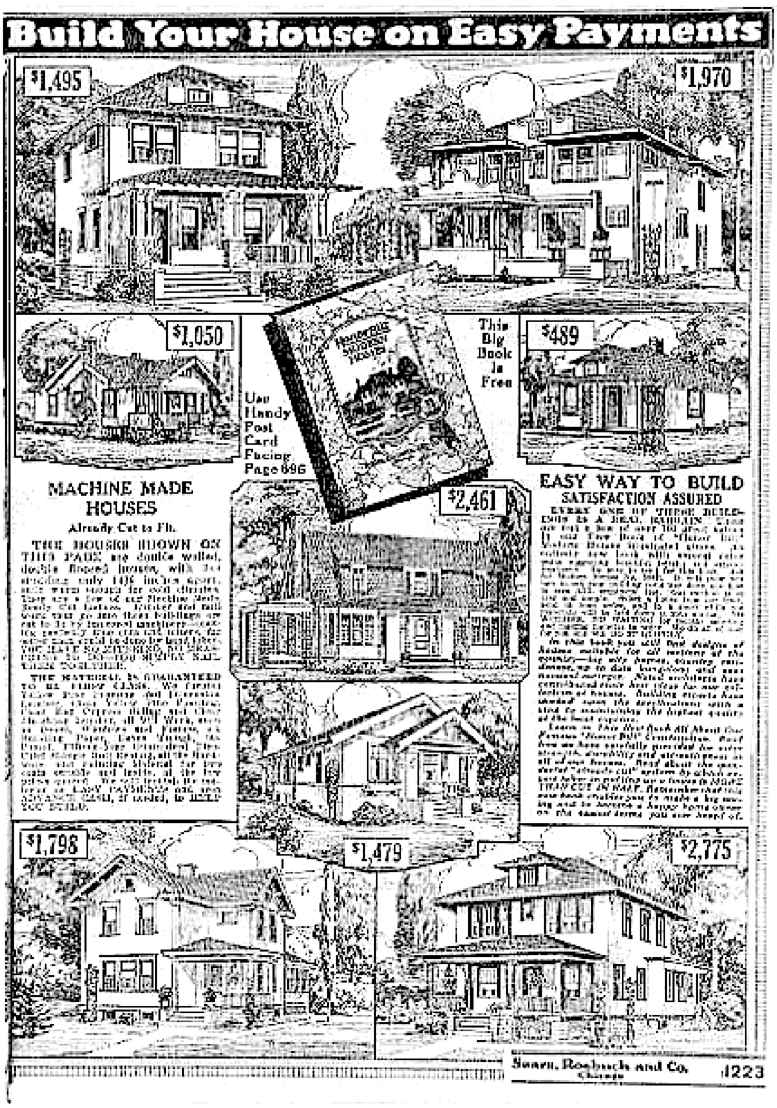


Figure 3.5 - Machine Made Houses in 'The Sears Roebuck' catalogue (Kliment, 2003)

In the 1940's, Walter Gropius developed the 'Packaged House', which was a factory based, mass-production system to manufacture highly customizable homes. He wrote, "It is by the provision of interchangeable parts that (we) can meet the public's desire for individuality and offer the client the pleasure of personal choice and initiative without jettisoning aesthetic unity" (Larson, 2000). Unfortunately this venture was ultimately a failure because the factory system that was developed was unable to economically deliver customized solutions.

Eventually the company was forced to produce no more than a few standard models that looked cheaper than a conventional home, cost more, and offered less personalization. When the company shut down, less than 200 homes had been produced (Herbert, 1984).

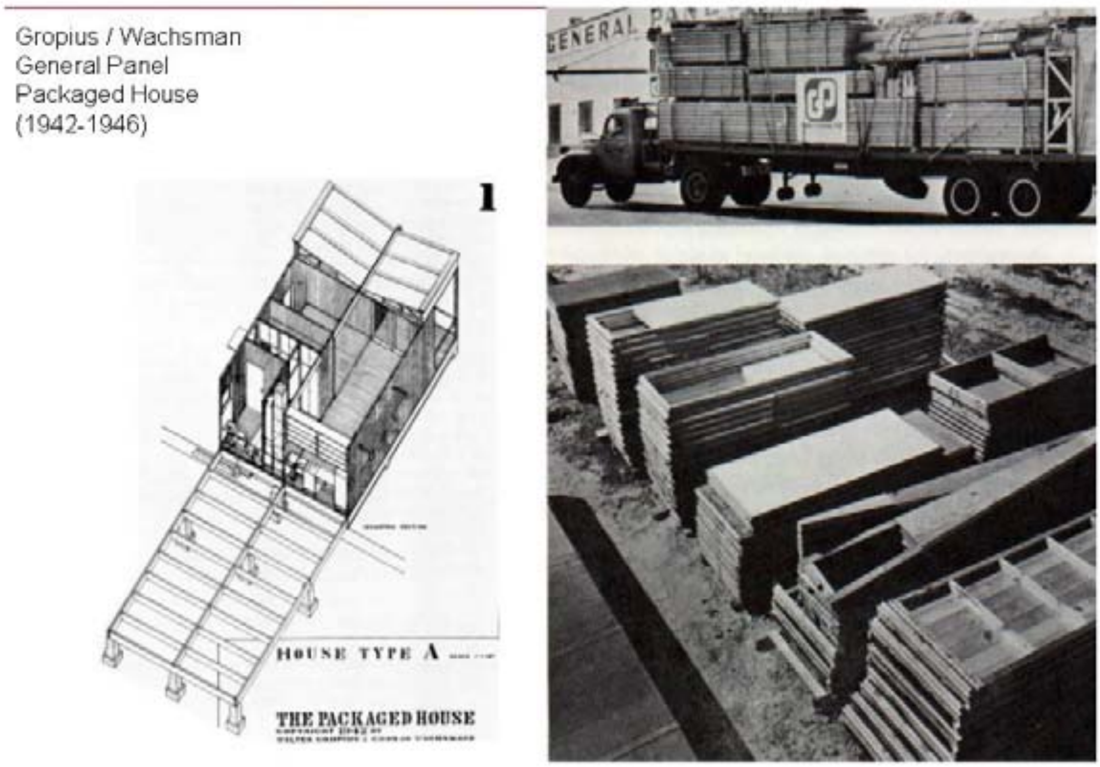


Figure 3.6 – The 'Packaged House' of the 1940's (Herbert, 1984)

Factory built housing can take a number of forms and is applicable to 2D and 3D building components and sub-assemblies, or to entire buildings (Sparksman *et al.*, 1999). This type of construction process is closer to a manufacturing paradigm (Barlow, 1999) than the current trade- and site-based Australian practices. Mass-customisation, differs from the traditional concept of pre-fabrication, in that it provides for a fully flexible, user specified product, which can cater for irregular and unique shapes and layouts.

Mass-customisation has already taken a strong foothold in the furniture industry. According to a white paper by the MIT Open Source Building Alliance (OSBA, 2006) cabinetry fabrication is perhaps the most sophisticated home-related industry. The trend is towards 'lights-out' production by taking advantage of information technology and automated CNC (computerized numeric control) production equipment. As equipment costs decline, even small shops are becoming automated, allowing both high-production and 'batch quantities of one'. The trade publication, Wood and Wood Products predicts that "a trend for the year 2002 may be mass customization . . . every customer has some special needs. To satisfy them and maintain a competitive edge, the only way to do this is to customize products."

As can be gleaned from the historical examples quoted earlier, it has been envisaged for quite some time that the construction industry, particularly in residential construction, will move more and more into the 'factory', and away from the 'site'. In Australia to date, this shift has only been partially realised (mainly through pre-nailed frames and manufactured roof trusses), and is occurring very slowly, primarily within the constraints of traditional construction practices. The exception to this is the domain of 'kit homes' and in a few larger 'affordable housing' developments (Karim *et al.*, 2002). However, this change in philosophy is a broader market driver in other parts of the world, particularly Scandinavia, and Japan, due to the harsh winters, and the shorter window of time available for site-based activities during construction.

An outline and conceptual framework for pre-assembly and pre-fabrication in construction that was developed in the UK is shown in Figure 3.7. Timber-related issues are highlighted in yellow.

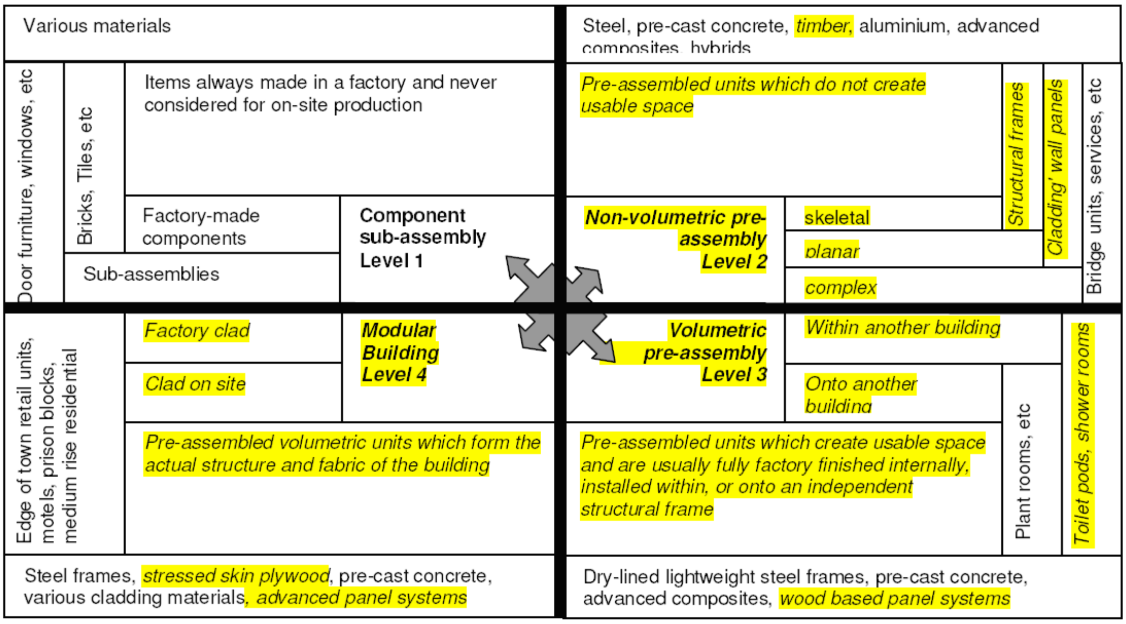


Figure 3.7 – Pre-assembly in construction (Gibb, 2001)

A study by Becker (2005), used the conceptual framework in Figure 3.7 to assess the potential for greater uptake of prefabrication in house construction in Australia, New Zealand, Canada, United Kingdom and Sweden. In the findings of this study it is concluded that all of the countries studied are at 'Level 2' (refer to Figure 3.7) which focuses on pre-assembled frames and cladding. Australia is in fact less advanced than this, as factory-built walls with claddings and/or linings are generally not produced.

The majority of the benefits of factory-constructed houses stem from the potential for process integration (Manufactured Housing Research Alliance, 2003; Naim and Barlow, 2002). These benefits include:

- Reduced cost
- Increased quality
- Reduced environmental footprint (incl. waste, emissions, recyclability)
- Improved energy efficiency and indoor environment quality

- Optimized and integrated design and construction
- Greater control over materials supply chain
- Quicker build time
- Improved worker safety

Although there are compelling arguments as to why such innovations would be beneficial, there is an underlying client and market resistance to adoption in many markets, including Australia. This resistance is prevalent in the UK, and has been studied by Robert Gordon University (Laing *et al*., 2001; Edge *et al*., 2002). Its causes can be traced to a range of social, perceptual and psychological factors, rather than technical or financial.

In North America however, manufactured housing is gaining a bit of a foothold, based on it's already established 'affordable housing' niche, and in 2001, it was in fact the fastest growing segment of the housing market (Wilden, 1995). It is predicted that within the next decade, that the factory built housing industry in the US will be propelled beyond this market and will play a more central role in fulfilling the nation's housing needs (Manufactured Housing Research Alliance, 2003).

Despite current resistance, it is likely that in the longer-term, the shift to off-site manufacturing in house construction will also increase in the Australian market. This will have big ramifications for the timber industry in Australia, if it is unable to embrace or compete with others that adopt this approach. However, in reality, timber construction systems are ideally suited to off-site manufacturing due to their light weight and ease of manufacture and processing. The current network structure and supply chain is also already adapted to this construction model in some sense through the widespread adoption of prefabricated roof/floor trusses and wall frames.

Modern technologies such as computer assisted design, CNC machine tools, advanced supply chain management, just in time production, the internet, new materials, new production techniques, and other tools and ideas position the industry to be more likely to succeed in this domain where it has failed in the past (Lawrence, 2003).

3.4 Demographics and social change

According to Professor David Foot (Foot, 1996), a leading demography expert, "Demography – the study of human populations – is the most powerful and most underutilized tool we have for understanding the past and foretelling the future". This is especially true for the housing market, which is changing in-line with the significant shifts in the demographics of Australia's population. As with many parts of the developed world, the population is ageing and the birth-rate declining. The 70-to-84 age group is projected to increase from 1.5 million in mid-2004 to 3.1 million by 2025. Over the same period, the 85+ age group will more than double from 325,000 to 770,000. As identified in the Building Construction Technology Roadmap (Copper Development Centre, 2004) this will result in the need for lower maintenance homes, and flexible floor plans to meet changing needs that come with aging. It is also predicted that a higher proportion of single occupancy (higher density) dwellings will be required in the future due to decreasing birth and marriage rates (Schuler and Adair, 2003). On top of these significant demographic changes, there also is an increasing lifestyle trend whereby people

want to live closer to coastal regions, which have higher susceptibility to natural disasters, higher exposure classifications for durability, and generally higher design wind speeds.

3.5 Workforce issues – skills shortages and industry consolidation

There is a shortage of qualified tradesmen to work on building sites in Australia, with the existing skills-base ageing fast. Implications of this may be that construction practices which depend on large skilled labour component could become less competitive in the future. This is likely to drive future decreases in site-based construction practices and a corresponding shift towards factory built housing and components. Similar skills shortages in the USA, Europe and Japan are already forcing the homebuilding industries in those regions towards a more industrialised construction process (NAHB, 1999; Schuler and Adair, 2003);

In Australia, of the approximately 30,000 builders active in 1992, the top 100 accounted for 17 per cent of the market for dwellings, while in 2004 it is predicted that the top 100 builders will supply 51 per cent of this market (Copper Development Centre, 2004). The implications of this are that there is a more consolidated industry, with a reduced proportion of small players. This could result in a potential increase in the uptake of innovative technologies, and an increase in capital investment, since in a more consolidated industry, small percentage profit gains can easily cover the costs of investment for the larger players. However in contrast to this, it is often the case that the smaller builders are the most willing to take a risk with new technologies (See Innovation and Technology Adoption).

3.6 Human health

There is an increasing awareness of human health and well-being issues related to the manufacture, installation, use, demolition and de-commissioning of all construction products. Occupational health and safety, indoor air quality and environmental toxins are particularly prominent issues.

Indoor environmental quality (IEQ) is recognised as a significant environmental and health problem in most developed countries. Modern populations typically spend 80 to 90% of their time indoors, whether at home, work or elsewhere (IAQWG, 2003). Formaldehyde and other emissions from some glued wood products and panels can adversely affect indoor air quality, but the majority of emissions come from furnishings and fit-out. In contrast to this, some studies indicate that use of wood in interior environments may have a positive effect on people's sense of well-being in that environment (Ridoutt *et al.*, 2002). Currently in Australia, there is no direct regulation or certification/labelling of products regarding such emissions but this could change soon.

Another human-health driven issue is ecotoxicity, which refers to the impact from release of toxic substances during the life cycle of building on an ecosystem, and includes all toxic chemicals released into the environment. Examples of wood products which have received attention due to toxicity include CCA treated timber (which is currently being phased out in Australia) and MDF.

Technologies which facilitate human health benefits through enhanced IEQ, reduced ecotoxicity and better OH&S are worthy of examination in this study.

3.7 Market demand and business potential

Market and business drivers are probably the most critical considerations when it comes to the success or failure of a technology or product in the fiercely competitive, cost driven, residential construction sector. Housing consumers are highly risk averse and sensitive to fashions and trends, so builders will rarely adopt new technologies unless they are satisfied that they will not adversely influence their customer's preferences (Koebel *et al*., 2004).

Many of the business drivers that lead to successful development and adoption of new technologies are imposed externally via regulatory imposts as has been clearly demonstrated in Australia of recent times with changes to termite regulations, introduction of energy efficiency provisions and changes to OH&S requirements on building sites.

New technologies that satisfy consumer demands and that also offer significant economical benefit to both the consumer and builder as well as having a sound technical and code basis (National Evaluation Service, 2002) are those most likely to succeed.

3.8 Regulatory environment

Building and other regulations cover a wide range of technical and design issues related to residential construction, and is too broad a topic to cover comprehensively here. Instead, some of the key drivers based around regulatory issues, which are most relevant to residential and light-industrial timber construction, in the context of this project, are summarised in the following points:

- The Australian Building Codes Board is committed to sustainability 'regulation', particularly in areas that can be more easily quantified, such as waste reduction and operational energy usage.
- There is already a mandatory 'five star' energy rating (for heating and cooling) implemented for housing in some parts of Australia. Because of the prescriptive nature of this provision, suspended timber ground floors are being replaced in Class 1 buildings due to energy requirements that favour systems with high thermal mass (i.e. concrete)
- There is a trend towards 'performance-based' building codes and standards rather than prescriptive, or deemed-to-satisfy regulations, although this has been on the cards for a long time with only marginal progress. The philosophy is that this will encourage more innovative products and technologies to enter the market. The dominant standard (AS 1684) for timber-frame construction (Standards Australia, 2006) is a deemed-to-satisfy standard, although the design criteria are given in part 1 of this standard, specific performance criteria are not spelt out clearly.
- Possible further regulation of toxic emissions to indoor spaces (from glues, coatings, treatments, etc). This will mainly effect fit-out and furniture rather than structural products. (see 'Human Health')
- Regulations are in place and undergoing further development for bushfires which discourage the use of timber in the 'external zones' around houses.

3.9 Aesthetic trends

Although not identified as a major drive in heavy construction, aesthetic trends can have a big influence on consumer behaviour in the residential sector, and are a significant driver which cannot be ignored. Although this is not specifically ‘technology’ related, products, systems and technologies which are adaptable in terms of their ability to fit in with a range of architectural and aesthetic styles are desirable by the industry and the market.

4. Innovation in the timber-framed construction industry

4.1 Innovation and technology adoption

The adoption and diffusion of innovative and new technologies can provide substantial benefits to the residential timber construction sector in Australia. In broad categories, these benefits may include:

- Increased housing affordability
- Increased (or maintained) market share and profitability
- Enhanced product quality and durability
- Reduced environmental footprint

Although the benefits are potentially large and widespread, patterns of innovation adoption in the residential construction sector are highly variable and largely unpredictable. The construction industry has often been referred to as a 'laggard' (see Figure 4.1) because of it's perceived tardiness in adoption of new technology (CERF, 1996). This could be partly due to the fragmented nature of the industry (and it's supply chains) which can act as a barrier to adoption. But despite this, some technologies which could demonstrate a clear and immediate benefit have been adopted quickly and widely (e.g. builders were amongst the 'innovators' in being the first universal adopters of mobile phones).

Innovation adoption and diffusion has been studied extensively in the fields of management theory, sociology, marketing, economics and others. Everett Rogers is a pioneer in this area of research, and his model of innovation adoption, shown in Figure 4.1, has been widely adopted in itself. Detailed background information and review of the general theories and models of innovation diffusion and adoption can be found in Rogers (1995), Wolfe (1994) and Boer and During (2001).

In summary, this literature indicates that a broad range of activities and technologies can be considered as innovative, and that the adoption and diffusion of these is dependent on many factors, including the industry context and structure. A summary of general determinants of Adoption and Diffusion is shown in Figure 4.2.

Boer and During (2001) further categorise innovation into three areas:

- Product
- Process
- Business system

This categorisation has been applied in studies of innovation in the wider forest-products sector (Hovgaard and Hansen, 2004), and is also appropriate for residential construction innovation. Other studies and reviews of innovation adoption, more specific to house construction can be found in (Koebel *et al.*, 2004), Ball (1999), Bengston and Gregersen (1992), Blackley and Shepard (1996) and Goverse *et al.*, (2001).

4.2 Impediments to adoption of new technologies and products

In 2004, an extensive US-based study attempted to find out the circumstances under which residential housing innovations become standard industry practices, using survey data gathered from builders (Koebel *et al*., 2004). It contains a detailed review of barriers and impediments to innovation in residential construction, and identified similar impediments to a host of previous studies (NAHB Research Center, 1990; Dibner and Lemer, 1992; CERF 1996; Jafee and Stavins, 1995; NAHB Research Center, 1991; Koebel, 1999; Ball, 1999; Fell *et al*., 2002). In summary, these impediments include:

- Cyclical nature of construction.
- Dominance of small firms.
- Lack of integration of the industry, particularly the heavy reliance on subcontractors.
- Diverse building codes with local peculiarities in details and administration.
- Lack of product approval systems that establish and certify to well-recognized performance criteria.
- Lack of access to information about new products.
- Inadequate education and training on products and materials, installation techniques, and methods of operation and maintenance.
- Exposure to liability.
- Required acceptance by the finance and insurance industries.
- Limited funding for research.
- Resistance to innovations from homebuyers.
- Lack of clear means for moving new technology from government and university research labs to field-testing.
- Poorly developed links between universities and the construction industry.
- Low levels of government support for technology development.
- Changes in ownership over the long service lifetimes of buildings.
- Inadequate flow of information within the industry and between the industry and manufacturers.
- Adversarial relations in design and construction related to fixed-price contracts.
- Inadequate capital for deployment.
- The high cost of deployment.
- Management ingenuity.
- High discount rates.
- Low impact of technology on profit.

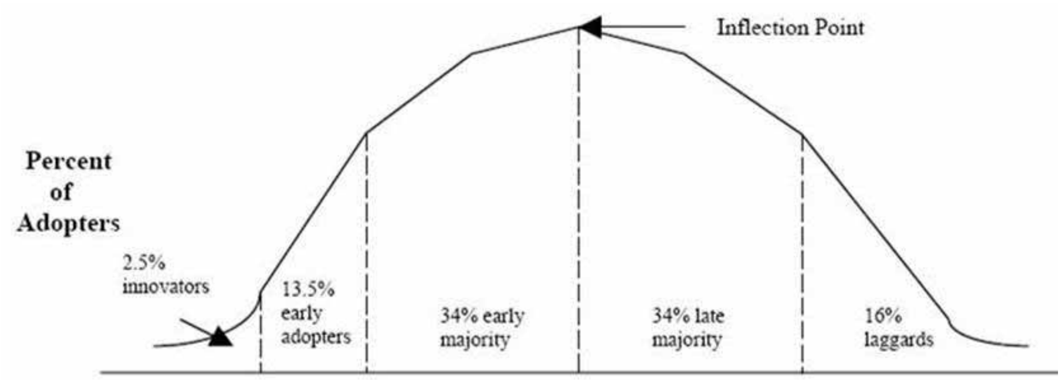


Figure 4.1 – Rogers' Model of Innovation Adoption (Rogers, 1995)

Adopter's Human Resources	Adopter's Organizational Structure	Adopter's Organizational Culture and Decision Process
▪ Skills ▪ Motivation ▪ Commitment ▪ Specialization and professionalism ▪ Technical knowledge resources ▪ Managerial attitudes and support	▪ Size and resources ▪ Centralization ▪ Flexibility ▪ Communication/ administrative intensity ▪ Complexity ▪ Formalization	▪ Innovation proneness ▪ Organizational support for innovation ▪ Technology champions ▪ Cooperation and openness ▪ Orientation (outward v. inward) ▪ Organizational position and role of decision maker
Adopter's Market Context	**Industry Characteristics**	**Communication Channels and Social Networks**
▪ Location ▪ Competitive strategy ▪ Market scope ▪ Growth strategy ▪ Knowledge of competitors' behavior ▪ Unionization	▪ Regionalization ▪ Concentration ▪ Heterogeneity ▪ Inter-firm competitiveness ▪ Growth rate ▪ Wage rates ▪ Government regulation	▪ Mass media ▪ Word-of-mouth ▪ Opinion leaders ▪ Professional and trade associations ▪ Boundary spanners ▪ Informal and indirect links
Technical Attributes of the Innovation	**Economic Attributes of the Innovation**	**Supplier/Vender Characteristics**
▪ Divisibility ▪ Learning by doing ▪ Complexity-crudeness ▪ Type of innovation (process or product) ▪ Complementarities required ▪ Relative improvements in old technologies ▪ Compatibility (values and practice) ▪ Communicability ▪ Relation to innovator product class schemas ▪ High, medium, and low tech ▪ Radical v. incremental	▪ Profitability ▪ Uncertainty/risk ▪ Expectations about future prices ▪ Expectations about future tech trajectory of innovation ▪ Labor saving v. materials saving ▪ Scale neutral v. lumpy ▪ Initial cost ▪ Continuing cost ▪ Rate of recovery of cost ▪ Time savings ▪ Start-up investment	▪ Technical capabilities and support ▪ Communications skills ▪ Expertise in monitoring deployment ▪ Public relations

Figure 4.2 – Determinants of Adoption and Diffusion (Koebel et al., 2004).

4.3 Builders' attitudes to adoption of new technologies

The results of a 2004 survey on US builders (Koebel *et al*., 2004) found that the innovators in residential construction were less likely than other builders to be concerned about the impact of the innovation on profits, and are more concerned about being a leader in the industry than about monitoring other builders. It also found that regional and national builders, and builders with a focus on multi-residential, or factory-built construction had significantly higher innovation scores than others. Lower levels of innovation adoption were associated with localised, 'family-business' builders and those with a focus on land development and speculation. Although size was not determined to be directly related to innovation, larger builders were likely to be first to adopt new materials that offer a cost savings, improvement in production process, reduction in call-backs or exposure to liability. Smaller builders were found to be first to adopt technologies where high consumer awareness of a material exists, the price of the new technology is significantly higher than what it replaces, or if the home construction process must be substantially altered.

The survey respondents most frequently identified increased quality as a main benefit to their firms for adopting new building and construction products, materials and practices over the last five years (See Figure 4.3). The next most frequently cited benefits were creating an image as an innovative builder, meeting customer expectations, and reducing call-backs. The most commonly quoted impediment to adoption of new products, materials and practices were cost, and the fact that subcontractors do not usually want to adapt to new products and materials (see Figure 4.4). In addition, the respondents overwhelmingly agreed that they rely on established companies that stand behind their products.

Benefits	Percent
Benefits over the last 5 years:	
Helping to comply with codes and regulations	25%
Decreasing costs	20%
Creating an image of our firm as an innovative builder	41%
Increasing productivity	24%
Increasing profit	16%
Increasing quality	74%

Figure 4.3 – Benefits of Using New Building and Construction Products, Materials, and Practices From a Survey of US Builders (Koebel et al., 2004)

Impediments	Strongly Disagree (1)	(2)	(3)	(4)	Strongly Agree (5)
Building codes make it difficult to use new building and construction products and materials	13%	23%	38%	18%	9%
New building and construction products and materials generally cost more than ones we currently use	3%	12%	36%	35%	14%
Our customers prefer the "tried and true" and don't like nontraditional products or features	6%	26%	44%	22%	4%
It is dangerous to be among the first firms who try new things in our market	15%	24%	32%	22%	6%
Our bankers and insurance companies are hesitant to underwrite projects with new products and materials	27%	36%	29%	6%	2%
Manufacturers and suppliers generally do not provide enough support for new products	7%	27%	41%	20%	6%
Gaining competitive advantage by using new building and construction products and materials is not an important part of our company's business strategy	19%	29%	27%	19%	7%
Using new building and construction products and materials increases our risk of call-backs	9%	25%	41%	21%	4%
Subcontractors in our market do not usually want to adapt to new building and construction products and materials	3%	21%	33%	31%	11%
Our construction workers find it difficult to learn a new way of building	8%	24%	36%	26%	6%
Our firm only uses new building and construction products and materials from established companies that stand behind their products	1%	3%	19%	49%	28%

N=242 to 246 depending on question.

Figure 4.4 – Impediments for Using New Building and Construction Products, Materials, and Practices From a Survey of US Builders (Koebel et al., 2004)

5. Generic technologies and product types

Within the context of the drivers, challenges and opportunities discussed in the previous sections, the project consultants were directed to target specific technologies, products and systems to include in the database. In the next phase of this project, a compendium of more specific innovative technologies, products and systems will be compiled from the database. The compendium will contain detailed descriptions of these technologies and the benefits and limitations with reference to a range of categories and criteria which cover the issues outlined in this review. To set the scene for the next phase of this project, a brief outline of the 'generic' technology areas, product types and application areas that have been targeted by the consultants is given in the following sections.

5.1 New and composite materials

Residential construction is always seen as a large potential market for competing materials including plastic, concrete and metal. Complete replacement of wood by these materials is undesirable from the timber industry viewpoint, however the use of wood-composites may lessen the effect of any substitution by competing products, and open up possibilities of alliances with other resource industries. There is already widespread use of wood-metal composite products in flooring and roofing in Australia. New technologies such as 'nanotechnology' offer some potential benefits in the areas of timber coatings and wood/plastic composites. Some of the composite materials that may be worthy of examination include:

- ***Fiber-reinforced composites*** of various kinds. For example, Kasal and Heiduschke (2004) studied the application of fiber composite material using kevlar fibers in the reinforcement of laminated wood products. This is a potential replacement for glued-in steel rods, and could be used in localised areas of high across-the-grain stress (e.g. connections). Others have used aramid fibre fabric (Croci and Viskovic, 1999), and glass fibre composites for similar purposes (Davalos and Qiao, 1988; Dagher and Lindyberg, 1999).
- ***Wood-plastic composites*** (WPC), refer to any composites that contain wood (in any form) and thermosets or thermoplastics. Although these have been around for decades, new processing and recycling technologies, advanced additives (Wolcott, 2003) and the phase-out of some chemically-treated wood products may foster increased interest in WPCs in the future. A good overview of WPCs can be found in Clemons (2002).
- ***Wood-concrete composites*** such as timber and fibre-reinforced concrete decks for use in residential construction are gaining acceptance. One example of such a system is the one studied by Heiduschke and Kasal (2003) in which composite action is achieved by pouring high-strength steel-fibre reinforced concrete into circular openings through the thickness of a vertically laminated wood deck.
- ***Other*** advanced composite systems which combine wood products with recyclable or reusable materials are also desirable.

5.2 Manufacturing and prefabrication technologies

The industrialisation of the house construction process has been identified as a key driver for the future (see Drivers, Challenges and Opportunities for the Future). In response to this, technologies and processes which foster industrialised construction may be increasingly important. Currently, the Australian industry utilises some basic manufacturing technologies, such as pre-nailed framing and prefabricated trusses. Whilst these technologies are relatively mature, opportunities may exist in extended technology and manufacturing systems that take a more 'whole of house' approach to analysis, design and construction. Mass customisation is an example of one such generic technology (Barlow, 1999). Panelised construction [such as Structural Insulated Panels or SIP ([Tracey, 2000)] is another generic technology example. A big advantage of SIP and other panel-type systems is that they are particularly well-suited to mass-customisation, or factory-manufactured construction processes.

It is therefore desirable to examine factory manufactured and customisable systems and processes that produce both:

- Volumetric units (modular or customisable)
    - Room by room
    - Entire houses
- Non-volumetric units (customisable)
    - Advanced panels for whole house with in-built services
    - Structural insulated panels
    - Stressed skin panels and floors
    - Factory clad/lined timber-framed panels

5.3 Light framing advances

Conventional site-constructed light-frame construction has a significant market inertia in Australia. Technologies and products which enhance the existing practices would be amongst the most readily adopted, and therefore should also be examined in this study. These include:

- Frame and truss systems
- Recurrent 'skeleton frame' systems
- Ring beam systems
- Factory fabricated supply/install timber framed floor systems
- Jointing
- Bracing and anchorage systems
- Glued/jointed products
- Engineered wood products

5.4 Alternative construction systems

Wood-based alternatives to light-frame construction systems are included in the study. Despite the fact they represent a threat to conventional light frame construction, there may be some potential for light frame to complement or be part of a hybrid with such systems, or for generic technologies used for alternative systems to be applied to light frame methods. Examples of alternative construction systems include:

- Solid tilt-up panels

- Wooden block and box beam
- Roundwood and manufactured logs
- Post and beam

5.5 Thermal and acoustic insulation systems and technologies

Innovative, high-performing and price competitive insulation systems that facilitate high acoustic and thermal performance of light frame construction systems are included in the study. Such technologies are important in overcoming perceptions of poor performance.

5.6 Treatment technologies

Chemical and other treatment technologies which enhance the in-service performance (durability and fire-resistance) of timber products, have a positive impact on environmental sustainability of wood products because of the longer service life that they facilitate (Preston, 2000). This benefit must be traded off against any Ecotoxicity or health impacts that may result in the production, use and disposal of treated products. New, 'low-toxicity' treatments for durability and fire resistance (e.g. Yamaguchi, 2005) have been identified as a priority for the viability of the forest products industry (Showalter *et al.*, 2003) and are worthy of investigation in this study.

5.7 Multi-residential timber-framed construction (MRTFC)

Demographic changes are driving an increased demand for MRTFC (see section 'Demographics and Social Change'. There are some technological challenges which need to be addressed if timber-based products are to have an increased impact in this growing market sector (Wallace *et al*., 1998) these include:

- ***Fire and noise*** rating requirements for multi residential construction, specifically, floor and wall systems that demonstrate efficient airborne and structure borne sound attenuation. An example of fire and noise rated design technologies for timber frame construction can be found in Evans (2005)
- ***Economic efficiency***, compared with alternatives, of timber-based floor and wall systems with high fire and noise resistance, and ease of construction.

5.8 Connection, bonding and jointing technologies

Connection design and construction/manufacture is critical to the performance of wood products and structural systems. New bonding and connection technologies which are appropriate for structural applications have the potential to improve site and/or factory construction methods, and assist in the development of new-generation composites and engineered wood products. 'Breakthrough' technologies of this type [eg. mechanically induced friction welding (Wieland *et al.*, 2005)] have been identified as an industry priority (Showalter *et al*., 2003) and may be worthy of examination.

5.9 Light-industrial applications

Potential opportunities exist outside of residential construction (O'Connor *et al.*, 2004; Buchanan, 2005), however this study is limited to single storey 'light framed'

commercial/industrial buildings. Key 'problem areas' (O'Connor *et al*., 2004 which need to be overcome to facilitate market entry into this sector include:

- ***Fire and nois***e rating requirements, as for MRTFC
- ***Cost competitiveness*** with steel and concrete alternatives
- Lack of ***expertise*** in design community

Technologies which overcome these barriers are worthy of investigation. For example:

- The use of ***small dimeter round timbers*** (e.g. Cantrell *et al*., 2004)
- ***Jointing technology*** for pinned and moment resisting frames, and
- Factory prefabricated ***'tilt-up' techniques***

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